




Economics of rhizobia and azospirilla co-inoculation in irrigated common bean in commercial and family farming

Abstract – The objective of this work was to evaluate the economic viability of the co-inoculation with *Rhizobium tropici* and *Azospirillum brasilense* in the Pérola cultivar of common bean (*Phaseolus vulgaris*), under sprinkler irrigation, in commercial and family farming in the states of Minas Gerais and Goiás, Brazil. For the analysis of economic viability, data from seven field experiments that evaluated the agronomic performance of common bean co-inoculated with *R. tropici* and *A. brasilense*, at six different sites, in three cropping seasons, were used. In these experiments, the treatments consisted of: non-inoculated control; N-fertilizer treatment; and different doses and forms of inoculum application. The economic analysis was performed based on market prices and indices as a function of the grain production of the different treatments. Economic viability was analyzed using the partial budgeting method. The best economic performance was obtained with the treatment *R. tropici* + three doses of *A. brasilense* sprayed on plants, which resulted in return rates of 90% in Goiás and 114% in Minas Gerais, for commercial farming, and of 13% in Goiás for family farming. For commercial and family farming, the production cost when using N fertilizer is 5.0 and 8.5% higher, respectively, than that with the co-inoculation of two doses of *R. tropici* and three doses of *A. brasilense*.


Index terms: *Phaseolus vulgaris*, market price, partial budgeting, profit.

Economia da coinoculação de rizóbio e azospirilo em feijão-comum irrigado em produção comercial e familiar

Resumo – O objetivo deste trabalho foi avaliar a viabilidade econômica da coinoculação de *Rhizobium tropici* e *Azospirillum brasilense* na cultivar Pérola de feijão-comum (*Phaseolus vulgaris*), sob irrigação, em produção comercial e familiar, nos estados de Minas Gerais e Goiás. Para a avaliação da viabilidade econômica, foram utilizados dados de sete experimentos de campo que avaliaram o desempenho agrônomo do feijoeiro-comum coinoculado com *R. tropici* e *A. brasilense*, em seis locais diferentes, em três anos agrícolas. Nesses experimentos, os tratamentos consistiram de: controle, sem inoculação; fertilização com nitrogênio; e diferentes doses e formas de aplicação dos inóculos. A análise econômica foi realizada com base nos preços e nos índices de mercado, em função da produção de grãos dos diferentes tratamentos. Já a viabilidade econômica foi avaliada com o método orçamentário parcial. O melhor desempenho econômico foi obtido com o tratamento *R. tropici* + três doses de *A. brasilense* pulverizado nas plantas, o que resultou em taxa de retorno de 90% em Goiás e de 114% em Minas

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Gerais, nas produções comerciais, e de 13% em Goiás, nas produções familiares. Na agricultura comercial e familiar, o custo de produção com uso de fertilizante nitrogenado é 5,0 e 8,5% superior, respectivamente, ao da co-inoculação de duas doses de *R. tropici* e três de *A. brasilense*.

Termos para indexação: *Phaseolus vulgaris*, preço de mercado, orçamento parcial, lucro.

Introduction

Common bean (*Phaseolus vulgaris* L.) is grown in three annual crop seasons in Brazil. The first is during spring-summer, mainly in the Southern and Southeastern regions of the country. The second occurs during summer-autumn in the Southern, Southeastern, and Midwestern regions. Finally, the third is during winter, in tropical areas under sprinkler irrigation, especially in the states of Minas Gerais, São Paulo, Goiás, Distrito Federal, Tocantins, Mato Grosso, and in the western region of Bahia (Silva et al., 2012).

According to Embrapa Arroz e Feijão (2020), in 2017, common bean production in the first and second crop seasons was 1.20 and 0.88 million tons, respectively. The area harvested with common bean was 723.1 and 759.6 thousand hectares, respectively, with yields of 1,667 and 1,159 kg ha⁻¹, in the first and second harvests. The irrigated crop produced 539 thousand tons of common bean, harvested in 207 thousand hectares, with an average yield of 2,598 kg ha⁻¹. The irrigated common bean crop represents 25.9 and 14.0% of the common bean production and area harvested in the country, respectively.

In this context, the increasing use of new technologies and cultural practices is becoming necessary in order to obtain greater yields to guarantee a more profitable common bean production system for producers, who usually face soil and phytosanitary problems inherent to each production system, high production costs, product price fluctuations, and an increasingly demanding market. Therefore, not only the adoption of new common bean varieties with proven high yields, but also the proper management of crops, is key to the success of common bean cultivation.

Among the technological innovations to improve the performance of common bean crops and to obtain a higher profitability at reduced costs, stand out some inoculant strains of proven effectiveness in biological nitrogen fixation and in promoting plant growth, such

as *Rhizobium tropici* and *Azospirillum brasilense*, respectively. Due to these characteristics, these inoculants may allow reductions in the use of nitrogen fertilizer in the common bean crop and promote the growth of plants (Brito et al., 2015; Souza & Ferreira, 2017).

Studies about the efficiency of nitrogen fertilization on common bean plant growth and yield have already been carried out (Argaw et al., 2015; Sorato et al., 2017). Nitrogen fertilization has been coupled with the inoculation with biofertilizers, such as the Semia 4077 (CIAT 899) and Semia 4080 (PRF 81) commercial strains (Brito et al., 2015). These researches highlight the importance of having knowledge of the variety and the conditions of development of the crop to produce grains. However, the obtained results are still controversial since the grain yield obtained with fertilization with 20 kg ha⁻¹ N, together with the inoculation with the CIAT 899 strain of *R. tropici*, was equivalent to that when using either up to 80 kg ha⁻¹ N (Soares et al., 2016) or 160 kg ha⁻¹ N (Brito et al., 2011).

Contrastingly, Peres (2016) found that the co-inoculation with *R. tropici* and *A. brasilense*, the inoculation with *R. tropici*, the inoculation with *A. brasilense* associated with 40 kg ha⁻¹ N as top dressing, and only the application of 80 kg ha⁻¹ N as top dressing do not provide yield increases, when compared with the control without inoculation and with 40 kg ha⁻¹ N as top dressing. However, Souza & Ferreira (2017) observed that the co-inoculation with *R. tropici* and *A. brasilense* resulted in yield increases of about 5 and 26%, respectively, in comparison with the application of 80 kg ha⁻¹ N and with a single inoculation with *R. tropici*.

Although there are reports of the advantages of the use of co-inoculation over nitrogen fertilizers, there is still no known economic analysis available.

The objective of this work was to evaluate the economic viability of the co-inoculation with *Rhizobium tropici* and *Azospirillum brasilense* in the Pérola cultivar of common bean, under sprinkler irrigation, in commercial and family farming in the states of Minas Gerais and Goiás, Brazil.

Materials and Methods

The analysis of the economic viability of the co-inoculation technology in common bean was

based on data from seven field experiments reported in Souza & Ferreira (2017), which were carried out in six different Brazilian municipalities (Cristalina, Goianésia, Itaberaí, and Santo Antônio de Goiás in the state of Goiás; and Paracatu and Unaí in the state of Minas Gerais) in three crop seasons (2013, 2014, and 2015). The cropping system was commercial production farming, with irrigation via a central pivot sprinkler, in all municipalities, except in Goianésia, where it was family farming, with sprinkler irrigation using electric pumping.

In these field experiments, the aim was to evaluate the agronomical performance of the Pérola common bean cultivar, of the “carioca” commercial grain type, when co-inoculated with *R. tropici* (Rt) and *A. brasilense* (Ab). The treatments consisted of: non-inoculated control (NI), 80 kg ha⁻¹ N fertilizer (NfT) as urea (178 kg ha⁻¹), two doses of Rt in seeds, two doses of Rt in seeds plus one dose of Ab in seeds (Rt+Ab1s), two doses of Rt in seeds plus two doses of Ab in seeds (Rt+Ab2s), two doses of Rt in seeds plus two doses of Ab sprayed on plants (Rt+Ab2p), and two doses of Rt in seeds plus three doses of Ab sprayed on plants (Rt+Ab3p). Economic viability was calculated considering the operational costs related to: the desiccation of the area, with 4.0 L ha⁻¹ glyphosate by mechanized spraying; soil fertilization, consisting of 300 kg ha⁻¹ of the 00-30-10 N-P₂O₅-K₂O formula; seed treatment, with 0.15 L ha⁻¹ of the thiamethoxam insecticide and 0.06 kg ha⁻¹ of the carboxin + thiram fungicides; ant control, with 0.50 kg ha⁻¹ of the sulfluramid formicide; weed control, with 0.30 L ha⁻¹ of the clethodim herbicide; phytosanitary treatments, with 0.40 and 1.00 L ha⁻¹ of the abamectin and chlorpyrifos insecticides, respectively, and with 1.50 and 1.50 L ha⁻¹ of the procymidone and triphenyltin hydroxide fungicides; irrigation via central pivot, estimated at 1,000 kWh ha⁻¹ of electric energy consumed for an average common bean yield of 49 bags of 60 kg ha⁻¹ each; mechanized harvest, carried out with the Ceiflex 3000T reaper machine (Indústrias Colombo, Pindorama, SP, Brazil); grain collection, threshing, and bagging, using the Master Grãos threshing machine (Miac Máquinas Agrícolas, Pindorama, SP, Brazil); and post-harvest costs, including grain reception, drying, cleaning, and storage, calculated as 1.8% of the production value.

To calculate the total cost of production, other additional costs were also taken into account, such

as those with: Programa de Garantia da Atividade Agropecuária, the Brazilian agricultural and livestock insurance program; private technical assistance, totalizing 2% of the operational costs; and social security, obtained from Instituto Nacional de Seguridade Social, the national institute of social security, and calculated as 2.2% over the sales of the production.

Calculations were performed similarly for both the commercial and family farming systems; the difference was that, for the later, costs with sprinkler irrigation were included. This cost was estimated at 277 kWh ha⁻¹ of electric energy consumed for an average common bean yield of 25 bags of 60 kg ha⁻¹ each.

The economic analysis of the cropping system was performed according to Guiducci et al. (2012), considering the economic surplus proposed by Avila et al. (2008), assessments of the technical coefficients of the Pérola common bean cultivar, and field visits to the regions with the studied technology by the producers, technical-assistance technicians, and technical staff of Embrapa Arroz e Feijão.

The technical coefficients of common bean were processed on a production cost worksheet, prepared in Microsoft Excel, and crossed with the average unit prices of the production factors in the markets of the states of Goiás and Minas Gerais for each study year. Factor and product prices for 2013 and 2014 were updated according to the general price index of Fundação Getúlio Vargas (FGV), for which the base was April 2015 = 1.00, and to the price received by the common bean producers at the time of harvest, for which the base was September 2015 = 1.00.

The economic balance of the cropping system was determined based on the partial budgeting method, where the unit costs of the production factors are calculated, focusing on the increase in the gross revenue coming from the additional cost of the impacting variable, which, in this case, is the inoculant in different dosages and number of applications. By the analysis of the marginal benefit (Baye, 2010), a cropping system is adopted based on the economic value of the co-inoculation, i.e., when the additional revenues are higher than the additional costs of the technology.

Data, except those of production costs, were first subjected to tests of normality and homogeneity of variances for each variable and then to the analysis of variance. When a statistically significant value

was confirmed in the F-test, at 5% probability, mean values were compared by Scott-Knott's test, also at 5% probability, using the Sisvar software (Ferreira, 2011).

Results and Discussion

The grain yield of the common bean crop grown in commercial farming varied from 2,351.15 to 3,149.35 kg ha⁻¹ in the state of Goiás and from 3,378.30 to 4,036.22 kg ha⁻¹ in Minas Gerais. The average of the seven treatments evaluated was approximately 47 and 60 bags of 60 kg ha⁻¹ each for the states of Goiás and Minas Gerais, respectively (Table 1). For family farming in Goiás, grain yield was lower, varying from 1,499.65 to 2,349.55 kg ha⁻¹, which is equivalent to 24.99 and 39.16 bags of 60 kg ha⁻¹, respectively (Table 2).

These results showed that grain yield differed significantly between the commercial and family farming systems. While the average grain yield of common bean under commercial farming was about 54 bags of 60 kg ha⁻¹, under family farming, it was approximately 35 bags of 60 kg ha⁻¹. This difference is explained by the technological level of each production system. In family farming, common bean production and supply to markets by the smallholders is constrained, mainly by the lack of productive assets, lack of improved varieties, and inadequate use of fertilizers (Birachi et al., 2011). In commercial farming systems, however, cutting-edge technologies

are adopted, such as geo-referred mechanization, last-generation agricultural inputs, and cultivars with a high productive potential (Farinelli & Lemos, 2010). Therefore, due to these differences, the productivity of commercial farming systems is higher than that of family farming.

In the state of Goiás, the Rt+Ab3p treatment resulted in about 53 bags of 60 kg ha⁻¹ each, which shows an increase of 4 bags of 60 kg ha⁻¹ in comparison with NfT. In the state of Minas Gerais, grain yield exceeded 4 tons per hectare (67.27 bags of 60 kg ha⁻¹) in Rt+Ab3p, resulting in about 9 bags of 60 kg ha⁻¹ more than those of the NfT treatment (Table 1). Several authors reported the positive effect of the co-inoculation with *R. tropici* and *A. brasilense* on the grain yield of common bean (Hungria et al., 2013; Souza & Ferreira, 2017), which is probably related to the synergy of these microorganisms when combined, leading to better results than those of single inoculation (Bárbaro et al., 2008).

The production costs of the common bean crop also varied according to the treatments. Under commercial farming, the NI treatment showed the lowest production costs of 3,429.18 and 3,565.17 R\$ ha⁻¹, respectively, in the states of Goiás and Minas Gerais. For both states, NfT had the highest production costs of 3,924.99 and 3,964.42 R\$ ha⁻¹, respectively (Table 3). Similarly, under family farming, the NI treatment showed the lowest production cost of 2,358.00 R\$ ha⁻¹ and Nft, the highest of 2,977.81 R\$ ha⁻¹ in Goiás (Table 2).

Table 1. Common bean (*Phaseolus vulgaris*) grain yield when subjected to different nitrogen-supplying treatments in an irrigated commercial farming system in the states of Goiás and Minas Gerais, Brazil⁽¹⁾.

Treatment ⁽²⁾	Goiás ⁽³⁾		Minas Gerais ⁽⁴⁾	
	Grain yield (kg ha ⁻¹)	Equivalence in product (bags of 60 kg ha ⁻¹)	Grain yield (kg ha ⁻¹)	Equivalence in product (bags of 60 kg ha ⁻¹)
NI	2,351.15b	39.19b	3,491.33b	58.19b
NfT	2,927.59a	48.79a	3,502.03b	58.37b
Rt	2,698.26a	44.97a	3,378.23b	56.30b
Rt+Ab1s	2,730.45a	45.51a	3,480.40b	58.01b
Rt+Ab2s	2,882.96a	48.05a	3,608.39b	60.14b
Rt+Ab2p	2,835.98a	47.27a	3,786.30a	63.11a
Rt+Ab3p	3,149.35a	52.49a	4,036.22a	67.27a
Average	2,796.53	46.61	3,611.84	60.20

⁽¹⁾Means followed by equal letters, in the columns, do not differ by Scott-Knott's test, at 5% probability. ⁽²⁾NI, non-inoculated control; NfT, fertilization with 80 kg ha⁻¹ N as urea (178 kg ha⁻¹); Rt, seed inoculation with two doses of *Rhizobium tropici*; Rt+Ab1s, seed inoculation with two doses of *R. tropici* and one dose of *Azospirillum brasilense*; Rt+Ab2s, seed inoculation with two doses of *R. tropici* and two doses of *A. brasilense*; Rt+Ab2p, seed inoculation with two doses of *R. tropici* plus spraying of two doses of *A. brasilense* on plants; and Rt+Ab3p, seed inoculation with two doses of *R. tropici* plus spraying of three doses of *A. brasilense* on plants. ⁽³⁾Average of the Itaberaí, Santo Antônio de Goiás, and Cristalina municipalities of the state of Goiás. ⁽⁴⁾Average of the Unai and Paracatu municipalities of the state of Minas Gerais. Source: data adapted from Souza & Ferreira (2017).

The production cost of NfT in the commercial and family farming systems was about 5.0 (Table 3) and 8.5% (Table 2) higher than those of the Rt+Ab3p treatment, respectively. This occurs because the use of N fertilizers, as urea, represents an expressive percentage of production costs and may vary according to several factors. In their study, Gerlach et al. (2013) observed that the application of a dose equivalent to 90 kg ha⁻¹ N represented 14% of the total operational cost.

The gross revenue also differed among the treatments. Under commercial farming, the lowest gross revenue was found for the NI treatment in Goiás, and the greatest values were obtained for Rt+Ab2p and Rt+Ab3p in Minas Gerais (Table 3). Under family farming, Rt+Ab3p resulted in the best gross revenue (Table 2). The net revenue values, obtained by subtracting the production cost from the gross revenue and evaluated only for commercial farming, were higher for the Rt+Ab2s and Rt+Ab3p treatments in both Goiás and Minas Gerais.

The average production costs in the state of Minas Gerais were higher than those in Goiás, considering the product equivalence of 4 bags of 60 kg ha⁻¹ each. The average gross revenue was also higher, reaching 12 bags of 60 kg ha⁻¹. The net income in Minas Gerais was, on average, of 29 bags of 60 kg ha⁻¹, which was also higher than that in Goiás, of 19 bags of 60 kg ha⁻¹ (Table 3). The net revenue of Rt+Ab3p was greater than that of the NfT treatment with 80 kg ha⁻¹ N; however,

in some instances, the use of rhizobial inoculation plus 20 kg ha⁻¹ N results in a net revenue similar to that of the application of 160 kg ha⁻¹ N (Pelegri et al., 2009).

The gross revenue seems to have significantly affected the benefit-cost ratio, which followed a similar pattern. In the state of Goiás, under commercial farming, the lowest benefit-cost ratio was observed for the NI treatment, while, in Minas Gerais, the highest value was obtained for Rt+Ab3p (Table 3). Under family farming, both NfT and Rt+Ab3p presented the highest benefit-cost ratio (Table 2).

The economic balance showed that, under commercial farming in the state of Goiás, the gross revenue increased from 14.76 to 33.95% for Rt and Rt+Ab3p, respectively, compared with that of the NI control. Considering that the production cost of these same treatments varied from 0.95 to 5.17%, respectively, the best marginal benefit was around 12 bags of 60 kg ha⁻¹, resulting in a rate of return of 89.6% (Table 4). In Minas Gerais, the gross revenue varied from -1.89 to 9.08% for Rt and Rt+Ab3p, respectively. Taking into account that the production cost varied from 0.03 to 6.03% for Rt and Rt+Ab3p, respectively, the best marginal benefit was of around 7 bags of 60 kg ha⁻¹, resulting in a rate of return of 113.7% for the state.

Likewise, under family farming, the lowest increase of 2.53% in the gross revenue was found for the Rt treatment. However, greater increases of 56.67 and 56.28% were observed for NfT and Rt+Ab3p,

Table 2. Economic analysis of common bean (*Phaseolus vulgaris*) grown in an irrigated family farming system, when subjected to different nitrogen-supplying treatments in the municipality of Goianésia, in the state of Goiás, Brazil⁽¹⁾.

Treatment ⁽²⁾	Economic indicator								
	Grain yield		Production cost		Gross revenue		Net revenue		Benefit-cost ratio ⁽³⁾
	(kg ha ⁻¹)	(bags of 60 kg ha ⁻¹)	(R\$ ha ⁻¹)	(bags of 60 kg ha ⁻¹)	(R\$ ha ⁻¹)	(bags of 60 kg ha ⁻¹)	(R\$ ha ⁻¹)	(bags of 60 kg ha ⁻¹)	
NI	1,499.65 b	24.99 b	2,358.00	29.99	1,965.04 b	24.99 b	-392.96 b	-5.00 b	0.83 b
NfT	2,349.55 a	39.16 a	2,977.81	37.88	3,078.69 a	39.16 a	100.88 a	1.28 a	1.03 a
Rt	1,537.55 b	25.63 b	2,404.12	30.58	2,014.70 b	25.63 b	-389.42 b	-4.95 b	0.84 b
Rt+Ab1s	1,598.60 b	26.64 b	2,438.67	31.02	2,094.70 b	26.64 b	-343.97 b	-4.38 b	0.86 b
Rt+Ab2s	1,791.70 b	29.86 b	2,477.04	31.51	2,347.72 b	29.86 b	-129.32 b	-1.64 b	0.95 b
Rt+Ab2p	1,610.47 b	26.84 b	2,492.79	31.71	2,110.25 b	26.84 b	-382.54 b	-4.87 b	0.85 b
Rt+Ab3p	2,343.70 a	39.06 a	2,722.15	34.62	3,071.03 a	39.06 a	348.88 a	4.44 a	1.13 a

⁽¹⁾Means followed by equal letters, in the columns, do not differ by Scott-Knott's test, at 5% probability. ⁽²⁾NI, non-inoculated control; NfT, fertilization with 80 kg ha⁻¹ N as urea (178 kg ha⁻¹); Rt, seed inoculation with two doses of *Rhizobium tropici*; Rt+Ab1s, seed inoculation with two doses of *R. tropici* and one dose of *Azospirillum brasilense*; Rt+Ab2s, seed inoculation with two doses of *R. tropici* and two doses of *A. brasilense*; Rt+Ab2p, seed inoculation with two doses of *R. tropici* plus spraying of two doses of *A. brasilense* on plants; and Rt+Ab3p, seed inoculation with two doses of *R. tropici* plus spraying of three doses of *A. brasilense* on plants. ⁽³⁾Based on the prices paid for production factors, updated by the general price index of Fundação Getúlio Vargas (FGV) (base: April 2015 = 1.00), and on the prices received by the common bean producers during harvest, updated by the general price index of FGV (base: September 2015 = 1.00). Source: results based on agronomic data from Souza & Ferreira (2017).

respectively. Considering that the production cost varied from 12.57 to 5.17% for NfT and Rt+Ab3p, respectively, the marginal benefit of Rt+Ab3p was greater than that of NfT, resulting in a rate of return of 3.39 and 12.82% due to each treatment (Table 5).

In the state of Goiás, common bean responded positively to the use of nitrogen, Rt inoculation, and

Rt+Ab co-inoculation, reflecting in yield increases, which provided greater economic gains. The Rt+Ab3p treatment effectively increased the gross revenue in 13.3 bags of 60 kg ha⁻¹, which represents a relative gain of about 34% compared with NI; this increase was caused by an additional cost equivalent to 1.36 bag of 60 kg ha⁻¹. Ndakidemi et al. (2006) performed

Table 3. Economic analysis of common bean (*Phaseolus vulgaris*) grown in an irrigated commercial farming system, when subjected to different nitrogen-supplying treatments in the states of Goiás and Minas Gerais, Brazil⁽¹⁾.

Treatment ⁽²⁾	Goiás ⁽³⁾		Minas Gerais ⁽⁴⁾	
	Value (R\$ ha ⁻¹)	Equivalence in product (bags of 60 kg ha ⁻¹)	Value (R\$ ha ⁻¹)	Equivalence in product (bags of 60 kg ha ⁻¹)
Production cost				
NI	3,429.18	26.33	3,565.17	29.69
NfT	3,924.99	29.64	3,964.42	33.01
Rt	3,521.75	26.58	3,566.85	29.70
Rt+Ab1s	3,521.43	26.76	3,609.70	30.06
Rt+Ab2s	3,588.27	26.88	3,643.08	30.34
Rt+Ab2p	3,644.08	27.29	3,719.71	30.98
Rt+Ab3p	3,715.68	27.69	3,779.93	31.48
Gross revenue				
NI	5,102.79b	39.19b	6,987.32b	58.19b
NfT	6,461.69a	48.79a	7,008.73b	58.37b
Rt	5,958.08a	44.97a	6,760.96b	56.30b
Rt+Ab1s	5,988.12a	45.51a	6,965.44b	58.01b
Rt+Ab2s	6,414.71a	48.05a	7,221.59b	60.14b
Rt+Ab2p	6,312.19a	47.27a	7,577.65a	63.11a
Rt+Ab3p	7,042.80a	52.49a	8,077.81a	67.27a
Net revenue				
NI	1,673.61c	12.85c	3,422.15b	28.50b
NfT	2,536.70b	19.16b	3,044.31b	25.35b
Rt	2,436.33b	18.39b	3,194.12b	26.60b
Rt+Ab1s	2,466.69b	18.75b	3,355.74b	27.95b
Rt+Ab2s	2,826.44a	21.17a	3,578.52b	29.80b
Rt+Ab2p	2,668.11b	19.98b	3,857.94a	32.13a
Rt+Ab3p	3,327.12a	24.80a	4,297.88a	35.79a
Benefit-cost ratio ⁽⁵⁾				
NI	1.49b		1.96b	
NfT	1.65a		1.77b	
Rt	1.69a		1.90b	
Rt+Ab1s	1.70a		1.93b	
Rt+Ab2s	1.79a		1.98b	
Rt+Ab2p	1.73a		2.04b	
Rt+Ab3p	1.90a		2.14a	

⁽¹⁾Means followed by equal letters, in the columns, do not differ by Scott-Knott's test, at 5% probability. ⁽²⁾NI, non-inoculated control; NfT, fertilization with 80 kg ha⁻¹ N as urea (178 kg ha⁻¹); Rt, seed inoculation with two doses of *Rhizobium tropici*; Rt+Ab1s, seed inoculation with two doses of *R. tropici* and one dose of *Azospirillum brasilense*; Rt+Ab2s, seed inoculation with two doses of *R. tropici* and two doses of *A. brasilense*; Rt+Ab2p, seed inoculation with two doses of *R. tropici* plus spraying of two doses of *A. brasilense* on plants; and Rt+Ab3p, seed inoculation with two doses of *R. tropici* plus spraying of three doses of *A. brasilense* on plants. ⁽³⁾Average of the Itaberaí, Santo Antônio de Goiás, and Cristalina municipalities of the state of Goiás. ⁽⁴⁾Average of the Unaí and Paracatu municipalities of the state of Minas Gerais. ⁽⁵⁾Based on the prices paid for production factors, updated by the general price index of Fundação Getúlio Vargas (FGV) (base: April 2015 = 1.00), and on the prices received by the common bean producers during harvest, updated by the general price index of FGV (base: September 2015 = 1.00). Source: results based on agronomic data from Souza & Ferreira (2017).

an economic analysis in northern Tanzania and found that, compared with the uninoculated control, the inoculation of common bean increased grain yield, translating into a dollar profit increase of 66 and 92% in the Moshi and Rombo districts, respectively.

In the present study, the Rt+Ab3p treatment showed the best economic performance of co-inoculation. In the state of Goiás, it resulted in a marginal revenue of almost 12 bags of 60 kg ha⁻¹, at a rate of return of about 90% on the investment done within the cropping system (Table 4). In Minas Gerais, it resulted in a marginal revenue of about 7 bags of 60 kg ha⁻¹, at a rate of return of approximately 114%. In the latter state, Rt+Ab3p also caused an effective increase of 9.08 bags of 60 kg ha⁻¹ in the gross revenue, representing a relative gain of about 16% compared with the NI treatment.

The relevance of *Azospirillum* sp. inoculation, in association with other microorganisms or coupled with mineral nitrogen fertilization, has been reported for many crops, including grasses. In a study on the effect

of inoculation vs. nitrogen doses, Galindo et al. (2017) concluded that the inoculation with *A. brasilense* allows a more profitable corn (*Zea mays* L.) growth, regardless of the used nitrogen dose and source. The authors also found that grain yield is increased by the addition of 200 kg ha⁻¹ N, in the form of conventional urea, coupled with the inoculation with *A. brasilense*; however, the highest economic return is obtained with 100 kg ha⁻¹ N, as conventional urea, combined with inoculation.

The additional cost of using only nitrogen in the NfT treatment was equivalent to 7.88 bags of 60 kg ha⁻¹, with a marginal benefit of 6.28 bags of 60 kg ha⁻¹. Compared with the other co-inoculation treatments, Rt+Ab3p was an advantageous exception, because, at an additional cost of 4.63 bags of 60 kg ha⁻¹, it allowed obtaining a marginal benefit of 9.44 bags of 60 kg ha⁻¹ and a profitability of 13% on the investment made (Table 5). Although the use of inoculants in family farming systems by smallholders is not usual, the interest in this technology is growing over the years,

Table 4. Economic balance of common bean (*Phaseolus vulgaris*) grown in an irrigated commercial farming system, when subjected to different nitrogen-supplying treatments in the states of Goiás and Minas Gerais, Brazil.

Treatment ⁽¹⁾	Economic indicator							
	Gross revenue			Production cost			Economic viability	
	Equivalence in product (bags of 60 kg ha ⁻¹)	Increase ⁽²⁾ (bags of 60 kg ha ⁻¹)	Variation (%)	Equivalence in product (bags of 60 kg ha ⁻¹)	Additional costs ⁽²⁾ (bags of 60 kg ha ⁻¹)	Variation (%)	Marginal benefit (bags of 60 kg ha ⁻¹)	Rate of return ⁽³⁾ (%)
Goiás								
NI	39.19	-	-	26.33	-	-	-	48.8
NfT	48.79	9.61	24.52	29.64	3.31	12.57	6.30	64.6
Rt	44.97	5.79	14.76	26.58	0.25	0.95	5.54	69.2
Rt+Ab1s	45.51	6.32	16.13	26.76	0.43	1.63	5.89	70.1
Rt+Ab2s	48.05	8.86	22.62	26.88	0.55	2.09	8.31	78.8
Rt+Ab2p	47.27	8.08	20.62	27.29	0.96	3.65	7.12	73.2
Rt+Ab3p	52.49	13.30	33.95	27.69	1.36	5.17	11.94	89.6
Minas Gerais								
NI	58.19	-	-	29.69	-	-	-	96.0
NfT	58.37	0.18	0.31	33.01	3.32	11.18	-3.14	76.8
Rt	56.30	-1.89	-3.24	29.70	0.01	0.03	-1.90	89.6
Rt+Ab1s	58.01	-0.18	-0.31	30.06	0.37	1.25	-0.55	93.0
Rt+Ab2s	60.14	1.95	3.35	30.34	0.65	2.19	1.30	98.2
Rt+Ab2p	63.11	4.92	8.45	30.98	1.29	4.34	3.63	103.7
Rt+Ab3p	67.27	9.08	15.61	31.48	1.79	6.03	7.29	113.7

⁽¹⁾NI, non-inoculated control; NfT, fertilization with 80 kg ha⁻¹ N as urea (178 kg ha⁻¹); Rt, seed inoculation with two doses of *Rhizobium tropici*; Rt+Ab1s, seed inoculation with two doses of *R. tropici* and one dose of *Azospirillum brasilense*; Rt+Ab2s, seed inoculation with two doses of *R. tropici* and two doses of *A. brasilense*; Rt+Ab2p, seed inoculation with two doses of *R. tropici* plus spraying of two doses of *A. brasilense* on plants; and Rt+Ab3p, seed inoculation with two doses of *R. tropici* plus spraying of three doses of *A. brasilense* on plants. ⁽²⁾Yield increase and marginal costs of each treatment compared with the non-inoculated control (NI=100). ⁽³⁾Based on the prices paid for production factors, updated by the general price index of Fundação Getúlio Vargas (FGV) (base: April 2015 = 1.00), and on the prices received by the common bean producers during harvest, updated by the general price index of FGV (base: September 2015 = 1.00).

Table 5. Economic balance of common bean (*Phaseolus vulgaris*) grown in an irrigated family farming system, when subjected to different nitrogen-supplying treatments in the municipality of Goianésia, in the state of Goiás, Brazil.

Treatment ⁽¹⁾	Economic indicator							
	Gross revenue			Production cost			Economic viability	
	Equivalence in product (bags of 60 kg ha ⁻¹)	Increase ⁽²⁾ (bags of 60 kg ha ⁻¹)	Variation (%)	Equivalence in product (bags of 60 kg ha ⁻¹)	Additional costs ⁽²⁾ (bags of 60 kg ha ⁻¹)	Variation (%)	Marginal benefit (bags of 60 kg ha ⁻¹)	Rate of return ⁽³⁾ (%)
NI	24.99	-	-	29.99	-	-	-5.00	-16.66
NfT	39.16	14.17	56.67	37.88	7.88	26.29	6.28	3.39
Rt	25.63	0.63	2.53	30.58	0.59	1.96	0.05	-16.20
Rt+Ab1s	26.64	1.65	6.60	31.02	1.03	3.42	0.62	-14.10
Rt+Ab2s	29.86	4.87	19.47	31.51	1.51	5.05	3.35	-5.22
Rt+Ab2p	26.84	1.85	7.39	31.71	1.71	5.72	0.13	-15.35
Rt+Ab3p	39.06	14.07	56.28	34.62	4.63	15.44	9.44	12.82

⁽¹⁾NI, non-inoculated control; NfT, fertilization with 80 kg ha⁻¹ N as urea (178 kg ha⁻¹); Rt, seed inoculation with two doses of *Rhizobium tropici*; Rt+Ab1s, seed inoculation with two doses of *R. tropici* and one dose of *Azospirillum brasilense*; Rt+Ab2s, seed inoculation with two doses of *R. tropici* and two doses of *A. brasilense*; Rt+Ab2p, seed inoculation with two doses of *R. tropici* plus spraying of two doses of *A. brasilense* on plants; and Rt+Ab3p, seed inoculation with two doses of *R. tropici* plus spraying of three doses of *A. brasilense* on plants. ⁽²⁾Yield increase and marginal costs of each treatment compared with the non-inoculated control (NI=00). ⁽³⁾Based on the prices paid for production factors, updated by the general price index of Fundação Getúlio Vargas (FGV) (base: April 2015 = 1.00), and on the prices received by the common bean producers during harvest, updated by the general price index of FGV (base: September 2015 = 1.00).

mostly in southern Africa (Giller et al., 2011), where the gross margin achieved by inoculant users was highly significant, reaching about US\$ 278 per hectare (Mutuma et al., 2014).

The results obtained in the present study are indicative of the importance of using *R. tropici* in the inoculation of common bean. In this line, Ndakidemi et al. (2006) found that inoculation increased the crop's profit in about 140 and 153% in the Moshi and Rombo districts, respectively, in northern Tanzania. In addition, the present study also showed that the co-inoculation of *R. tropici* and *A. brasilense* increased the rate of return of the crop in about 30%. Similarly, Galindo et al. (2018) reported that the co-inoculation with *A. brasilense* and *Bradyrhizobium elkanii* or *Bradyrhizobium japonicum* positively affected soybean [*Glycine Max* (L.) Merr.], resulting in a profitability index of about 64%.

Conclusions

1. In commercial and family farming, the production cost when using nitrogen fertilizer is, respectively, 5.0 and 8.5% higher than that with the co-inoculation of two doses of *Rhizobium tropici* and three doses of *Azospirillum brasilense* in the Pérola cultivar of common bean (*Phaseolus vulgaris*).

2. In family farming, the co-inoculation of *R. tropici* with three doses of *A. brasilense* in common bean results in a profitability of 13%.

3. The net income of the co-inoculation treatments in the state of Minas Gerais is 20 bags per hectare in common bean higher than that of the same treatments in the state of Goiás, Brazil.

4. In commercial farming, the co-inoculation of two doses of *R. tropici* and three doses of *A. brasilense* in common bean has a return rate of 90% in Goiás and of 114% in Minas Gerais.

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